AN INDEPENDENT TECHNICAL REVIEW OF THE EXPERIMENTAL AUTONOMOUS VEHICLE (EAVE) PROGRAM

of the

RESEARCH AND DEVELOPMENT PROGRAM
CONSERVATION DIVISION
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1.0 BACKGROUND OF PROGRAM AND REVIEW

The Experimental Autonomous Vehicle Program (EAVE) of the U.S. Geological Survey (USGS) is a part of a research and development program to provide advanced technology to support the Geological Survey's regulatory operations on the Outer Continental Shelf (OCS). The development of advanced technology under this program is intended to enable the acceleration of the development of the petroleum resources in the context of the USGS's Congressionally mandated responsibilities:

> Protect against losses to human life and property, injuries to personnel, damages to the environment, and waste of natural resources by means of an organized and systematic approach to the preleasing and leasing of potential or known oil and gas sites on the OCS.
>
> Establish requirements for safe drilling and production operations on the OCS.
>
> Ensure that the oil and gas industry complies with regulations, safe practices, and environmental safeguards through the development and enforcement of stringent requirements.
>
> Maintain an R&D capability for improving the functions the USGS is required to do.

The EAVE program specifically addresses the technologies required for the inspection of offshore structures. There are technologies available for the inspection of oil production platforms that are presently installed in the OCS. However, as platforms are established in deeper and more hostile waters, improved techniques will be required that can accomplish inspection more rapidly, safer, and at less cost than current techniques can provide.

The EAVE program has been underway since the Fall of 1977. Two organizations have been performing different segments of the program - the Naval Ocean Systems Center and the University of New Hampshire. In December of 1980, the USGS program manager, Mr. John Gregory, initiated actions to have the program independently evaluated by non-affiliated ocean engineeering experts. A two-day review of the program was held May 20-21, 1981. A list of participating evaluators is given in Appendix A. A list of contributing observers is given in Appendix B.

The two-day review resulted in numerous comments by the participants. The more substantive comments were summarized at the review by Dr. Victor Anderson of the Marine Physics Laboratory of the Scripps Institute of Oceanography and Dr. Robert Franscois of the Applied Physics Laboratory of the University of Washington and presented to the program manager and to the performing organization project managers: Mr. Paul Heckman of the Naval Ocean Systems Center for EAVE West and Dr. Robert Corell of the University of New Hampshire for EAVE East. This report is a more comprehensive set of program and project review comments as well as the summary information provided at the review meeting.

The review meeting and this summary report were technically coordinated by Mr. Denzil C. Pauli, an independent consultant and formerly Ocean Technology Program Director of the Office of Naval Research. Organizing support was provided by Mr. Kenneth Youngmann of EG&G, Inc.

2.0 OCS INSPECTION TECHNOLOGIES

Inspection of offshore oil production platforms during installation is a basic part of the USGS structural verification program. The inspections under the program to assure that the structure is sound are generally performed by third parties. Some of the most stressful conditions imposed upon the structure occur during its at-sea tow from port, its launch from the transport barge, and finally the installation operations of tilting and setting it on the sea floor. Industry follows up the initial inspections on a need to know basis that might result from storms, collisions, gradual deterioration, etc. The need for post-construction periodic inspections as part of the structural verification program has been considered by the USGS and by the National Research Council (NRC)[1]. However, at the present time, there is no government-required, post-installation inspection program.

The NRC study documented the types of inspections that are conducted either by industry for its quality assurance or by the USGS under the verification program. Tables 1 through 3 taken from the NRC study present the inspection needs, data requirements, types of sensors usable, and the types of available or future inspection equipment transporters. Table 4, also from the NRC study, outlines a suggested R&D program to support the USGS in its inspection efforts.

It must be recognized that there are wide differences in platform types as well as the environment to which they are exposed. North Atlantic, Gulf of Mexico, and Arctic waters represent three considerably different sets of environments. Even in the Gulf of Mexico vast differences exist in the water depths in which platforms are being

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[1] National Research Council, Inspection of Offshore Oil and Gas Platforms and Risers, National Academy of Sciences, Washington, D.C. 1979.

TABLE 1. INSPECTION NEEDS VS DATA REQUIRED FOR STEEL STRUCTURES

Inspection Needs \ Physical Properties		General Structural Integrity	Structural Deformation	Joint Separation	Joint Cracking	Corrosion Protection System Integrity	Corrosion Potential Measurements	Corrosion Thickness Measurement	Fouling	Scour	Nature and Location of Debris	Vibration	Tilt
GENERAL PERIODIC INSPECTION	**Above Water**												
	Existence of Corrosion					X		X					
	General Deterioration and Cracking		X	X	X			X					X
	Structural Distress	X	X	X	X								X
	Splash Zone												
	Corrosion					X	X	X					
	General Deterioration		X	X	X		X	X	X				
	Structural Deformation	X	X	X	X							X	
	Thickness Gauging							X					
	Weld Zones in Detail		X		X			X					
	Excessive Fouling								X				
	Submerged Zone												
	Member Missing	X										X	
	Structural Deformation	X	X	X	X							X	
	Excessive Scour									X	X		
	Corrosion-Protection System					X	X	X					
	Thickness Gauging							X					
	Weld Zones in Detail		X		X			X					
	Excessive Fouling								X				
	Presence of Debris										X		
	Repairs and Modifications		X	X	X	X	X	X					
EVENT-ORIENTED INSPECTION*	**Above Water**												
	General Structural Integrity	X	X	X	X	X							X
	Splash Zone												
	General Structural Integrity	X	X	X	X	X	X						
	Submerged Zone												
	General and Local Structural Integrity	X	X	X	X	X	X	X		X	X		X
	Corrosion Inspection Where Suspected						X	X					

*Requirements are the same for event-determined and periodic inspections.

TABLE 2. DATA REQUIRED VS SENSORS FOR STEEL STRUCTURES

Applicable Sensors	General Structural Integrity	Structural Deformation	Joint Separation	Joint Cracking	Corrosion Protection System Integrity	Corrosion Potential Measurements	Corrosion Thickness Measurement	Fouling	Scour	Nature and Location of Debris	Vibration Signature	Tilt
Eye	X	X	X	X	X		X	X	X	X		X
Television	X	X	X	X	X		X	X	X	X		
Film Camera	X	X	X	X	X		X	X	X	X		
Optical Scan	X	X	X		X			X	X	X		
Acoustic Scan	X	X							X	X		
Ultrasonic Thickness							X					
Radiographic				X								
Magnetic Particle				X								
Corrosion Potential					X	X						
Profile Gauge		X					X					
Straight Edge		X					X					
Accelerometers											X	
Ultrasonic Flaw Detection		X	X									
Platform Tilt and Level Gauge												X
Eddy Current				X								
NOTE: Cleaning is required for certain measurements:												
(a) Brush			X	X			X	X				
(b) Chipper			X	X			X	X				
(c) Water Jet			X	X			X	X				

TABLE 3. SENSORS VS TRANSPORTERS

SENSOR \ TRANSPORTER	SUBMERSIBLES					STRUCTURAL MOUNT	
		Tethered		Untethered			
	Divers	Manned*	Unmanned	Manned	Unmanned	Permanent	Temporary
Eye	X	X		X			
Television	X	X	X	X		O	O
Camera	X	X	X	X	R		O
Optical Scan	R	R	R	R	R		
Acoustic Scan	X	X	X	X	R		O
Ultrasonic Thickness	X	O	O	O	R		O
Radiographic	X	O	R	O	R		
Magnetic Particle	X	O	R	O	R		
Corrosion Potential	X	X	X	X	R	X	X
Profile Gauge	X	O	R	O	R		
Straight Edge	X	X	O	X	R		
Accelerometer						X	X
Ultrasonic Flaw	X	O	R	O	R		
Platform Tilt and Level Gauge							X
Eddy Current	O						
NOTE: Some sensors require preliminary cleaning:							
(a) Brush	X	O	R	O	R		
(b) Chipper	X	O	R	O	R		
(c) Water Jet	X	O	R	O	R		

*Without diver lockout, but includes one atmosphere diving suit.

PIPELINE INSPECTION DATA NEEDED

SENSORS \ DATA	Buckling	Displacement*	Strength	Cladding	Coating	Cathodic Protection	Erosion	Leaks	Corrosion
Eye	X	X		X	X		X	X	
Television	X	X		X	X		X	X	
Film Camera	X	X		X	X		X	X	
Acoustic Scan		X							
Coupon or Section							O		O
Pressure			X					X	
Flow Meter								R	
Ultrasonic Flaw			O	O	O		O		O
Magnetic Anomaly			O	O			O		O
Corrosion Potential						X			
Fluorimeter								X	

*Supports and unsupported spans.

SENSORS
X = Existing System
O = State-of-the-Art
R = R&D

TABLE 4. R&D NEEDED TO SUPPORT OCS INSPECTION AND MONITORING

R&D AREA	REPRESENTATIVE R&D TOPICS
Cleaning	Cleaning: Adapt the present Navy Work Systems Package for deep cleaning operations for commercial application by divers and submersibles.
Remote Sensing Devices	Television: Investigate the use of fiber optics cables and transmission and signal processing techniques to meet the bandwith requirements of remote underwater TV transmission for inspection purposes.
	Optical Scan: Develop a systems concept to exploit laboratory developments in rapid total scanning (laser mapping) of underwater structures.
	Acoustic Scan: Exploit acoustic imaging technology to cope with regimes of high turbidity and consequent limited visibility.
	Ultrasonic Thickness Gauge: Develop an instrument designed specifically for underwater use.
	Radiographic: Adapt existing instruments for use in unmanned submersibles. Eliminate radiation hazard to observers.
	Magnetic Particle Inspection (MPI): Develop MPI systems for tethered and untethered submersibles; extend depth capability beyond present 100 m limit.
	Corrosion Potential Meters: Package for use in unmanned submersibles.
	Sub-Bottom Profilers: Experiment to determine profilers' applicability for use in inspection of buried man-made structures such as platform foundations.
	Profile Gauge: Package for use with remote controlled vehicles.
	Accelerometers (Dynamic Analysis): Pursue and develop this technology.
	Ultrasonic Flaw Detection: Develop computer-aided processors for _in situ_ or real time interpretation.
Inspection Vehicles	Divers: Extend depth capability of commercially available saturated diving services. Adapt fiber optics to diver-carried data tethers to improve safety, to obtain greater transmission bandwith and immunity from electromagnetic interference.
	One-atmosphere Diving Suits (ADS): Improve tactile response of ADS, improve manipulators and include snap-on-tool capability; improve operator response in reduced visibility conditions.
	Manned Submersibles: Develop lightweight, expendable fiber optics links for communication and data transmission including observing underwater inspection from the surface.
	Unmanned Tethered Submersibles: Develop lightweight cables for fiber optics and power transmission (high data-rate feedback). Develop "intelligent" vehicles with minimum of operator feedback control required.
	Unmanned Untethered Submersibles: This embryonic technology area should be supported and systems development encouraged.
Pipeline Inspection and Monitoring	Develop devices for the measurement of internal corrosion in underwater platform risers.
	Develop leak detection flow meters.

placed. All of these factors impact upon the inspection effectiveness: the ability to inspect, the time required, cost, and the minimization of the risk to human life during inspection. And in turn, inspection effectiveness relates to the acceleration of the development of OCS oil production, particularly from the deeper and more hostile OCS waters.

3.0 EAVE

3.1 GOALS.

The Experimental Automonous Vehicles (EAVE) Program has the goal of developing technology for unmanned, free-swimming vehicles capable of performing inspection tasks on underwater pipelines and offshore structures. The Program is not vehicle development, nor is it the optimization of the various subsystems for unmanned submersibles. Instead, it is investigation of technologies existing in the scientific and technological communities for the purpose of establishing and demonstrating new ways of performing basic underwater tasks of potential importance to the Geological Survey's offshore regulatory mission.

3.2 APPROACH.

At the inception of the Program, two vehicles were already under development. At the University of New Hampshire, a free-swimmer was being devised that would use acoustics for both navigation and communications. This rather symmetrical vehicle offered the high manuevera-bility needed to move around structures. The Naval Ocean Systems Center project chose a torpedo-shaped configuration that was slated for optical fiber communications and for magnetometer navigation. This vehicle offered promise of higher speed operation which would be desired when navigating along underwater pipelines. In addition, its proposed magnetometers would be able to "follow" the pipelines even though buried. A unique opportunity was therefore presented to the Geological survey for sorting out the operational and technical parameters for free-swimmers. Accordingly, the U.S. Geological Survey seized this ideal opportunity to develop technology that is directly relevant to underwater inspection missions.

3.3 PROJECT COORDINATION.

At the beginning of the EAVE Program, the related, but separate activities of NOSC and the University of New Hampshire, were identified as EAVE-West and EAVE-East, respectively. At this time, a project interdependency net was developed that showed the basic technical direction that the two principal investigating agencies were to pursue. Initial technical coordination services were provided by NOSC. As vehicle and technology development progressed, the separate technical approaches tended toward non-redundancy and the single technical manager concept was replaced by using a principal investigator at each project site. Direct communications at principal investigator levels have proven adequate for avoiding a duplication of effort. Overall project coordination is now exercised at the USGS level.

3.4 INNOVATION AND TECHNOLOGY TRANSFER.

Several avenues are open for transferring technology being developed in the EAVE Program. Internal transfer to other USGS departments is of primary consideration. The petroleum industry, as prime owners of the candidates for underwater inspection, also may find the output of the EAVE Program suited to their use or for consideration in their design work, or related equipment. The output of the fiber optics work at NOSC has already been applied to a large scale development project in torpedo technology.

A key to success in transferring technology is project visibility and the quality of documentation. In this regard, several publications exist which describe work already accomplished. Further, the EAVE/E and EAVE/W principal investigators have provided many briefings to organizations interested in the development of technology for the underwater inspection mission.

4.0 EAVE PROGRAM REVIEW

4.1 PURPOSE.

The EAVE Program has been in progress for about three years. In this time several accomplishments have been achieved, and portions of the underwater inspection technology have had interesting demonstrations. However, the review of this work has generally been at the program level with little or no formal technical assessment of the EAVE activities. Accordingly, it was appropriate to assemble a group of technical experts who could review the technical quality of the EAVE work. Such a review would serve to establish the appropriate credibility for results achieved and to provide independent non-biased constructive criticism for current initiatives. The agenda for this review and the guidance provided for the principal investigators is provided as Appendix A. The members of the technical review group and other attendees are identified in Appendix B.

4.2 REVIEW STRUCTURE.

4.2.1 GENERAL REVIEW. A general review was presented for EAVE-W by Mr. Paul Heckman and for EAVE-E by Dr. Robert Corell. These sessions were a thorough overview of each program and, in general, provided the following:

a. An overview of the project history, including objectives and changes to EAVE related efforts

b. EAVE EAST/WEST as a system and as an assembly of technologies

c. Identification of the technologies under development, i.e., communications, navigation, sensors, etc.

d. A top level review of the Principal Investigator's technical approach to specific objectives

e. A statement of achievements versus goals

f. Current year and future plans

g. Documentation status

4.2.2 TECHNICAL BRIEFING. The majority of the time for the review was dedicated to detailed briefings by individuals directly responsible for task accomplishment. These sessions proved useful for verifying technical approaches and as a forum for exchange of concepts. The agenda in Appendix C cites the specific subjects discussed.

4.3 TECHNICAL PANEL REVIEWS.

After each project's technical sessions were complete, the Technical Review Group summarized their comments and developed an overall project assessment in private session. And finally, this information was presented for use by the USGS Program Manager and by each principal investigator.

The remainder of this report formalizes the activities and conclusions of the EAVE Technical Review.

5.0 TECHNICAL REVIEW OF EAVE WEST

5.1 GENERAL BACKGROUND.

The technological thrusts of the EAVE West project are those thrusts required to gain the capability to inspect offshore gas and oil pipe lines by unmanned, self-powered, remotely controlled vehicles.

Techniques that would be used in pipeline inspection employing a remote, unmanned vehicle include:

a. Pipeline Detection. A sensing system for the initial detection of the pipeline and subsequent tracking (navigating along the line).

b. Pipeline Inspection. Sensors for inspection of the pipeline. These might include optical (both television and photographic), electropotential, acoustic, as well as other special purpose sensors. A manipulator may be required for positioning sensors for detailed inspections.

c. Transmission Links. Means for transmitting inspection, position, and vehicle command information.

d. Navigation. Navigation sensors for position monitoring and/or command control.

e. Microprocessor Systems. On-board computer/memory systems for vehicle control and robotic decision functions.

The sensors and technologies used will probably be multipurpose. Thus, the sensors for detection of the pipe may well be part of the pipe-following system and may also have a role in inspection.

The type of vehicle required to test such technologies would be one having both a hover capability for detailed inspection and a fairly good underway speed for gross inspection and pipe-following operations. The NOSC vehicle, used in the EAVE West project, has a limited hovering capability and a 5-knot underway design speed.

5.2 SPECIFIC TECHNOLOGIES.

5.2.1. PIPELINE DETECTION AND TRACKING. Detection of the pipeline's magnetic characteristics has been chosen as the primary sensory technique for both the acquisition of the pipeline by the remote vehicle and for following the pipeline. Both visual and acoustic techniques are used by diver and shipborne inspection; however, such techniques suffer when pipelines are either buried by natural environmental processes or by deliberate operator burial to avoid pipeline damage from ship anchors and other hazards.

5.2.1.1. Magnetic Sensor. Two types of magnetic detection have been considered: passive and active. Both have relatively short ranges of detection - in the order of 10 to 30 feet. In the passive case, the small distortions of the normal earth's field by the magnetic properties of the pipe are detected through the use of magnetic field instruments such as total field and gradient magnetometers. Such instruments have been designed for marine operation for use by geophysicists for scientific purposes and by the Navy for mine and submarine detection. Variation in the magnetic distortions along a pipeline, such as a localized reversal of the pipe's field, may create difficulties for a sensor of this type to follow pipelines.

In the active type of magnetic sensor, an alternating magnetic field is generated by one coil. Usually, two other separate coils or magnetic cores, appropriately displaced from each other in space, pick up the generated field. Their signals are bucked against each other to produce a zero signal. External ferrous materials such as a pipeline cause a distortion in the generated field which, in turn, induces an imbalance in the pickup sensors resulting in a detectable signal. The frequency of the generated alternating field is important. Low frequency fields are more noisy; higher frequency fields (in the kilohertz range) require more power due to attenuation in the water. The lower frequency signals induce a magnetic flux in the ferrous material. High frequency fields generate eddy currents in the conductive skin of the ferrous or whatever other conductive material is present; the field caused by these eddy currents modifies and distorts the normally generated field giving rise to a detected signal. Active magnetic detectors have also been used by the Navy for the detection of mines and by explosive ordnance experts for the detection of unexploded ordnance. More simplified and less sensitive units are used by treasure hunters and by utility workers for locating city gas pipelines. They are also used for the inspection of reinforcement steel bars in offshore concrete structures.

5.2.1.2 Magnetic Tracking. Once the pipeline has been acquired by the EAVE West vehicle, it is intended that the magnetic field information be used to control the vehicle to follow the pipeline. Direction control of the vehicle would be accomplished by on-board processing of the magnetic field sensory data.

5.2.1.3 Project Goals of Magnetic Detection Technology Thrust. The magnetic detection/tracking technology goals of the program are the demonstration of the ability of using magnetic detectors for detection of petroleum pipelines and to navigate along the pipeline so that other appropriate sensors may be continously positioned for uninterrupted inspection of the pipeline.

5.2.1.4 Project Achievements in Magnetic Detection Thrust. Theory has been reviewed showing the positive feasibility of the technique for the detection of pipelines. The active type of detection sensor has been selected as most appropriate. Assessment of components to be used in the system has commenced. There are technological gaps at present involving component selection/testing which remain to be completed. The method of signal analysis for tracking purposes has yet to be determined.

5.2.1.5 Review Panel Comments.

a. Use of the active technique appears to be appropriate. However, further analytical work appears to be justified rather than basing the design on sketchy information on foreign sensors.

b. An analysis of power requirements for varous magnetic detection and tracking systems appears not to have been done. This requires an analysis of the sensors capability with respect to the depths to which pipelines might be deliberately or naturally buried. This analysis must be done in concert with an overall power analysis taking into account appropriate, available power sources.

c. A sea demonstration of the pipe acquisition and tracking capability will be critical to enhance the technology transfer to either industrial or USGS field inspection groups.

d. Because of the availability of onboard microprocessors for signal analysis, the investigators might consider the use of short pulse active systems in order to conserve vehicle power.

e. Technological transfer of available technology from Navy magnetic detection programs to this program has not been adequately explored.

5.2.2 INSPECTION TECHNIQUES. A number of inspection techniques might be appropriate for use on the pipeline follower. However, prior to any effort to provide any specific technique, it is important that a definitive analysis be made of pipeline inspection using remote sytems: What are the critical pipeline conditions to be identified and their magnitude? What is the topological change that is critical? If there is a leak, what might be the magnitude of the petroleum product that is of concern and how will that product move through the ocean? What is the effect of a cover over the pipe? Is corrosion to be identified or the state of the corrosion protection system? Would the sytem be used in conjunction with internal pipeline inspection devices such as "pigs"?

Once the inspection parameters are known, then the appropriateness of various sensors, such as fluorimeters or electropotential gradiometers, or acoustic transducers can be ascertained. The alternatives and how a particular remote vehicle inspection sensor fits within the overall inspection can then be projected before initiating the technological thrust to gain the appropriate capabilities.

5.2.2.1 Goals and Achievements. Efforts thus far have been directed to providing the vehicle, transmission links, command/control microprocessors rather than inspection technologies, per se.

Low-light-level TV, and acoustic sensors are readily available, as are fluorimetric and contact electropotential sensors. Underway measurement techniques of the pipeline's electropotential field by submersibles will be more difficult than that accomplished by ships. However, before technology developments are initiated in any of these areas, the needs, modes of utilization, and the associated magnitudes of the parameters to be measured during inspection require definition.

5.2.2.2 Review Panel Comments. As this is not a present technology thrust, the panel did not comment on this technology area.

5.2.3 TRANSMISSION LINKS. Fiber optic communication lines have been chosen for transmitting commands to the EAVE West vehicle and for sending navigation positioning data and inspection information to the control ship or offshore platform.

Many benefits accrue from the use of fiberoptic transmission lines as compared to electrical conductors. In the case of the conventional electrical cable tethers, strength members must be incorporated. By the time insulation material, sufficient copper signal wires, and the strength members are put together, a large cable is produced. To provide strength for countering currents or tow speeds, the size is further increased. Consequently, most of the power required to move the vehicle through the water is to overcome the drag of the tow cable. An alternative technology might be the wire communication link used in wire guided torpedoes. However, the bandwidth of such a system is useful only for 10-20 kHz while the bandwidth of a fiber optic link is in the megahertz range and can be used for video communications. While costs are relatively high for the fiber optic lines (two dollars per foot) it is expected that increased use will drive this cost down within the next few years.

5.2.3.1 Project Goals in Fiber Optic Transmission Line Technology Thrust. The technological goal of the fiber optic technology thrust is simply to provide a reliable, wideband communication link to the remote-controlled, self-powered inspection vehicle during launch, hovering, and continuous pipe following operations.

Funding for the initial portion of the fiber optical technology thrust was by the EAVE West Program. However, since early interest was obtained of several Navy development groups, the major funding for technological development in this area is now from the Navy.

5.2.3.2 Achievements of Transmission Link Technical Thrust. Fiber optic transmission links used in landborne telecommunications links do not have the strength or the stiffness characteristics required for underwater vehicle communications use. Consequently, a coating had to be designed to provide this additional strength and stiffness. Further, spooling the wire off at the underwater vehicle and at the ship from which the vehicle is launched required special techniques for winding the fiber onto the spool to prevent kinking during the unreeling. To prevent unintended despooling and jamming, the fiber is lightly glued as it is spooled - too great an adherence would prevent spooling and cause breakage; and too little would cause jamming and breakage. The technologies of winding, gluing, and spinning the wire out have been developed, using both the EAVE West funding and Navy funding. Tests using the EAVE West vehicle at sea remain to be done, however, and further problems may become evident.

Fiber optic communications links for use with EAVE West must be capable of providing communications in both directions - ultimately TV video and other sensed data from the vehicle and command control information to the vehicle. Couplers to provide this two-way communications have been built and tested.

All cables break, and especially in use at sea. The optical fibers will also be subject to abuse aboard ship in normal handling and means for quick splicing is a necessary technology that has been developed for EAVE West use. It is evident that EAVE West early efforts have initiated large funding for fiber optic work from the Navy.

Technology transfer involves many techniques, one of which is adequate documentation. A quite detailed, EAVE West technical report provides a summary of the fiber optic technology.

5.2.3.3 Technological Gaps. Simulated operations using the fiber optic transmission link to control the remote vehicle and calm water tests of paying out the optical fiber must be followed by the more severe at-sea tests on an instrumented range to identify the extent of operational problems/deficiencies and unforeseen technological gaps.

5.2.3.4 Review Panel's Comments. The technological gains that have been presented in the EAVE West fiber optic program are significant and well documented. It has been an excellent technological thrust.

5.2.4 NAVIGATION TECHNOLOGICAL THRUSTS. It is the intent of the EAVE West Program to make use of an on-board compass and the pipeline magnetic sensors for navigating to and along the pipeline. For monitoring the vehicle position, the EAVE West's program will not address new navigation position fixing technologies as they are either sufficiently available from commercial sources or will be available from the EAVE East Program.

5.2.5 MICROPROCESSOR CONTROL TECHNOLOGICAL THRUSTS. The vast microprocessor technology that has become available in the past 10 years enables compression of components and space required for control of the underwater vehicle and analysis of sensed data. Gaining versatility by using rather powerful microprocessors and supporting hardware modules can minimize hardware changes. A continual stream of software programming can be foreseen as the vehicle's tasks become more sophisticated. However, modularizing of the software will reduce reprogramming efforts.

The use of color in the remote vehicle control terminal can effectively provide additional differentiation of the operational problems faced by the operator.

5.2.5.1 Goals. Provide on-board computer power and software for vehicle control and a corresponding easy to operate control terminal.

5.2.5.2 Achievements. Tests have been conducted of the hardware and the software for controlling the vehicle both for preprogrammed and real time control. Preprogrammed tests have been conducted in water. Real time control tests are being planned to be conducted in conjunction with the fiber optic transmission link.

5.2.5.3 Technological Gaps. As inspection sensors are added to the vehicle, significant enlargement of the control requirements will occur. Many of these will not require technological advances, per se, but will require significant programming efforts. Robotic-type decision making with respect to the control of the vehicle and the inspection sensors, however, may well provide opportunities for advances in robotic technology.

5.2.5.4 Review Panel's Comments. The panel concurred in the keeping to one type of microprocessor and its supporting hardware to avoid unwarranted hardware and software rework. Further, the panel felt the modularizing of the software was the proper approach.

5.2.6 EAVE WEST ASSOCIATED AND TECHNOLOGY RELATED PROGRAMS (NON-USGS FUNDED). NOSC EAVE West project personnel have several other projects which are supported by Navy funding which, ultimately, will have a direct effect upon the USGS EAVE Program. The two which are most closely related are the:

Small manipulator development, and the
Artificial intelligence programs

The small manipulator program has developed to the point that it is ready for testing on the EAVE West vehicle. This manipulator has a 15-inch upper arm, a 9.75-inch forearm, and a set of 7.25-inch claws in series with their respective shoulder, elbow, and wrist pivots. Fully extended, the lift capability is 12.5 pounds in water.

The artificial intelligence program is a study of automatic computerized "decision making" by remote vehicles involved in working tasks. Thus far it has been a theoretical analysis.

5.2.6.1 Review Panel's Comments. The manipulator work is quite well documented. There may be an unfavorable interaction between the dynamic response characteristics of the vehicle and the manipulator. A good part of the artificial intelligence analysis outline as presented by the investigator is normal systems engineering; nevertheless, the panel felt that the paper presented a reasonably well structured approach.

6.0 EAVE EAST

6.1 GENERAL BACKGROUND.

The technological thrusts of the EAVE East project are those required to gain the capabilities to inspect offshore, fixed, petroleum drilling and production structures by unmanned, self-powered, autonomous or remotely controlled vehicles.

Techniques that would be used in structure inspection employing a remote, unmanned vehicle include:

a. Navigation. Navigation sensors for vehicle position monitoring and/or command control. The navigation system may include more than one set of subsystems.

b. Structure Inspection. Sensors for the inspection of the structure and of pertinent operating equipments such as valves, piping, seals, etc. Cleaning may be an important adjunct to certain types of inspection.

c. Transmission Links. Means for transmitting inspection, position, and vehicle-command information.

d. Microprocessor Systems. Vehicle and control station computer/memory systems for vehicle control and robotic decision functions.

Most likely the sensors used for each of the foregoing tasks will be separate entities. However, they may use common technologies. The various sensory data, navigation and inspection as well as command control will be tied together through microprocessors. A common transmission link may also be used for many of the data/command communications between operating personnel and the vehicle.

The type of vehicle required to test the technologies required for platform structure inspection must be capable of hovering and maneuvering among the legs and cross members of the structure in whatever ocean currents might be present. It must have self contained power for the mission period and have a load capability for the specific navigation and inspection tools which it must carry.

A major goal of an earlier phase of the EAVE East project was to show the feasibility of locating and tracking a pipeline by underwater sound. The emphasis has been shifted from pipe tracking to platform inspection. Pipe tracking efforts were completed in the fall of 1979. The platform inspection technology project was then initiated.

6.1.1 PIPELINE DETECTION/TRACKING BY UNDERWATER SOUND.

6.1.1.1 Technological Thrust. The primary technological thrust of the pipeline detection and tracking project was the development and testing of a concept for autonomous detection and tracking of a nonburied pipeline using echo sounding techniques.

6.1.1.2 Achievements. An open frame underwater vehicle having six thrusters and five degrees of freedom was constructed to serve as the test platform. A 5-foot diameter ring of 12 downward looking acoustic transducers, mounted below the vehicle, served as the sensors for the detection and tracking of the pipeline.

A pipeline detection logic was developed based on return time differences of ocean floor echoes from each of the transducers. An algorithm was developed to determine the pipeline orientation with respect to the vehicle. This information was then used to generate autonomous tracking signals which controlled the vehicle thrusters to enable pipeline tracking.

Tests of the vehicle, the acoustic detection system, and the autonomous tracking system were conducted to track a curved test pipe layed in a lake. The tests were successful but showed some deficiencies that could be surmounted by logic modifications and the addition of a simple compass. One such deficiency was the tendency for the vehicle to be forced by the logic to drift uphill during pipeline search modes.

6.2 PRESENT STRUCTURE INSPECTION TECHNOLOGICAL THRUSTS.

6.2.1 NAVIGATION.

6.2.1.1 Goals of Technological Thrust. The goals of the navigation technology thrust are to gain the capability: to monitor the position of the vehicle as it passes among the various underwater legs and cross members of a structure; to be capable of directing the vehicle to navigate along paths which will take it to specific inspection points within the structure interstices; and to provide maneuvering signals which will enable the vehicle to hold its position while performing inspection and associated tasks, i.e., placing of sensors on the structure and cleaning metallic surfaces.

6.2.1.2 Project Direction and Achievements. Acoustic navigation has been selected as the primary technique to be explored for monitoring the vehicle position and for navigating to specific inspection points on the structure. While not being addressed at the present time, inertial systems may be considered at a later time for localized short term navigation functions associated with sensor placement, cleaning, etc.

The primary problems that have to be overcome in the use of acoustic systems are those related to multipath echoes and the shadowing of transducers by platform structural members.

Leading pulse edge detection techniques are being employed to minimize multipath problems. Multiple baseline transducers are being used to minimize shadowing problems. Using the multiple transducers, a voting system is being developed for eliminating undesired data.

In-tank tests have been conducted of the accuracy and repeatability of the navigation system. Initial tests have indicated both an undesirable bias as well as too great a variance in transmission times.

Development of preprogrammed navigation between points from outside a structure to inspection sites within the structure is underway. The navigation preprogramming will take into account the size of the vehicle, necessary clearances, acoustic navigation errors, and the underwater architecture of the structure being inspected. Techniques for determining available paths between end points of the path are being analyzed.

Planning for a repeat of the acoustic error tests is underway as well as planning for summer lake tests of the EAVE East vehicle navigating through a simple test structure.

6.2.1.3 Technological Gaps. The acoustic navigation system being developed will probably not satisfy navigation requirements in the near vicinity of an inspection point. Variability of ocean currents around the structure; e.g., vortex shedding, reaction to cleaning and inspection techniques, and the time delay of navigation information plus shadowing and multipaths will all contribute to this problem. Thus, a hybrid navigation system may be required.

6.2.1.4 Review Panel's Comments. Navigation control is very dependent upon the vehicle dynamics and upon the environmental conditions. The dynamics of the vehicle have not been given sufficient consideration either through modeling or through tests. Even a crude model would be worthwhile. Yaw rate and vertical acceleration response are of particular importance.

It is not clear that the acoustic system can provide a rapid enough update to effectively close control loops to give a position accuracy of a few inches. If the positioning data is very accurate, then the error signals are small. However, if there is too great a time delay in obtaining the data (or if the errors are large) signals may be generated which may give rise to serious excitation in the vehicle dynamics. Navigation errors will be particularly sensitive to yaw rate and vertical accelerations.

The leading-edge pulse detection technique is probably good. However, the reinitializing technique for range acceptance needs closer investigation. Algorithms for self-calibration should be included in the navigation system. Also an algorithm utilizing space diversity to minimize shadowing should be considered.

The summer tests will probably reveal more problems. It would be highly desirable for the vehicle tests to be adequately instrumented and recorded so that analysis of the navigation tests can be quantitive.

6.2.2 INSPECTION TECHNOLOGIES. There were no inspection technologies under development and therefore none under this review. However, the interaction of inspection operations with the technologies being developed, i.e., navigation, should be given serious consideration in future efforts. Time effective cleaning operations as well as other inspection operations require holding the vehicle to close tolerances in a not very stable condition.

Inspection of BOPs and other production equipments may require different types of maneuvers. Various categories of inspection should be reviewed with respect to the types of maneuvers and other navigation/control information that might be necessary.

6.2.3 TRANSMISSION LINKS. The technology goal is to provide a reliable two-way data link between the remote vehicle and the on-site control personnel who in most cases would be located on the structure or a nearby ship. The data from the vehicle would include inspection information as well as certain vehicle navigation and control status data. Inspection techniques would probably include TV inspection.

6.2.3.1 Direction and Achievements. Other than navigation data transmission, there has been little current effort under the EAVE East project in transmission of inspection data. The 1979 EAVE East report discussed some efforts; however, not in technical detail.

The acoustical transmission of data will require a great deal more technical depth than has so far been presented in the EAVE Program either in reports or orally. Multipath problems put severe restraints upon the length of data streams and, thus, information bit rates.

While under certain conditions, the fiber optics transmission link developed under EAVE West would be of value, under many environmental conditions existing around the offshore structure the life of the link would be limited because of probable fouling and subsequent breakage. An acoustically transmitted, slow scan TV picture transmission system was demonstrated by NOSC a few years ago. The picture quality probably needs improvement for detailed inspection work. The French are also working in this field.

6.2.4 MICROPROCESSOR SYSTEMS. The goal of the microprocessor system is to provide a maximum of robotic control so that a minimum of real time controls are required for routine operations of the vehicle in its operational modes.

6.2.4.1 Direction and Achievements. It is the intent of the project for the microprocessor system to handle all of the data handling and control functions of the system: navigation calculations of present position, path calculations for future vehicle moves, manipulator control, inspection sensor controls, and data flows between the vehicle and the surface. A memory bank concept is projected that would include the underwater position of architectural features of the structure being inspected as well as the position of underwater production equipments. This memory would probably be located at the surface control station for complex structures.

Hardware and software for the vehicle control functions have been designed and tested. The hardware and software for the acoustic position fixing system have been designed and partially tested. The hardware and software for the path determination calculations are likewise in the test stage. Critical in-water integrated tests are scheduled for this summer.

6.2.4.2 Review Panel's Comments. The panel concurred with the making of a choice of microprocessors and then sticking to it rather than shifting to new more powerful ones as they become available. It also concurred with the modular hardware and software concepts being used.

One reviewer did question, however, whether the added microprocessors were being forced because of the need of additional memory or was it the desire to use the multiprocessor system concept.

7.0 GENERAL COMMENTS OF REVIEW PANEL.

The review panel was very appreciative of the two project groups - EAVE West and EAVE East - for making individual investigators available and their forthright presentations. This review not only provided a mechanism by which ideas, concepts, problems, and accomplishments of the two projects could be discussed, it also provided a technology transfer forum both to and from the EAVE investigators. The review comments of the panel are offered as positive suggestions and are to be taken within the context of the programmatic aspects of the USGS EAVE Program.

7.1 REVIEW PANEL'S COMMENTS COMMON TO EAVE PROGRAM IN GENERAL.

There were a number of constructive comments made by the Review Panel that were applicable to the EAVE Program - that is to both EAVE West and EAVE East projects. The underlying cause for some of the comments may be due to program restraints caused both by restrictions on funding and on programmatic responsibilities, or lack thereof within the USGS/DOI.

The inspection tasks that each of the vehicles were to perform were not specififed in sufficent detail so as to determine possible interactions of the inspection task with the other technologies involved, i.e., navigation and vehicle power requirements.

The dynamics of the vehicles had not been investigated to the degree necessary to determine possible short comings in their use as test beds. Two examples cited were: (a) for the West vehicle, the response of the vehicle while engaged in a hovering mode doing tasks using a manipulator; and (b) for the East vehicle, the response while navigating turns or operating in the path of structure-shedded vortices.

Both organizations could have made greater use of existing technology transferable to them: two examples are magnetic detection technology and acoustic navigation technology.

Both organizations are accomplishing excellent microprocessor and associated software work. However, overemphasis in this area at the sacrifice of other technologies may be occurring, i.e., magnetics and acoustics.

The quality of hard documentation that will enhance technology transferability is variable. The report on optical fiber technology is excellent; others are not so well documented, including citations.

Advances in artificial intelligence aspects will be important. However, there may be small semantic differences between what may be called the structure of artificial intelligence and that which is normally structured in systems engineering.

Neither vehicle has operated in the harsh at-sea environment. The two teams have been engaged in fair water test conditions. However, real environments may not have been sufficiently considered even at this early point in the technology developments.

APPENDIX A

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APPENDIX C

AGENDA FOR EAVE TECHNICAL REVIEW

May 20, 1981

TIME	SESSION NO.	SUBJECT
9:00 - 9:10 am	1	Program Manager's introductory remarks
9:10 - 9:20 am	2	Review Chairman's introduction
9:20 - 10:00 am	3	EAVE-West project briefing
10:00 - 12:00 am	4	EAVE-West technical review - Magnetics - Software - Artifical intelligence - Fiber optics - Manipulator
12:00 - 1:00 pm		Luncheon
1:00 - 3:30 pm		Continuation of EAVE-West Technical review
3:30 - 4:30 pm		Reviewers' critique session (closed)
4:30 - 5:00 pm	6	EAVE-West recapitulation

May 21, 1981

TIME	SESSION NO.	SUBJECT
9:00 - 9:45 am	7	EAVE-East project briefing
9:45 - 12:00 pm	8	EAVE-East technical review - Under sea structure inspection scenario - Microprocessor system - High resolution navigation system - Command computer - Control computer - Communication system

Agenda continued for May 21, 1981

TIME	SESSION NO.	SUBJECT
12:00 - 1:00 pm		Luncheon
1:00 - 3:00 pm		Continuation of EAVE-East technical review
3:00 - 4:00 pm	9	Reviewers' critique session (closed)
4:00 - 4:30 pm	10	EAVE-East recapitulation
4:30 - 5:00 pm	11	Summary and closing